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The Use of Bouts and Frequencies in the Evaluation of Hand Preferences for a Coordinated Bimanual Task in Chimpanzees (*Pan troglodytes*): An Empirical Study Comparing Two Different Indices of Laterality

William D. Hopkins,

Department of Psychology, Berry College and Division of Psychobiology, Yerkes Regional Primate Research Center, Emory University

Micheal J. Wesley,

Department of Psychology, Berry College and Division of Psychobiology, Yerkes Regional Primate Research Center, Emory University

Autumn Hostetter,

Department of Psychology, Berry College and Division of Psychobiology, Yerkes Regional Primate Research Center, Emory University

Samuel Fernandez-Carriba,

Division of Psychobiology, Yerkes Regional Primate Research Center, Emory University and Departamento de Psicología Biológica y de Salud, Facultad de Psicología, Universidad Autónoma de Madrid, Madrid, Spain

Dawn Pilcher, and

Division of Psychobiology, Yerkes Regional Primate Research Center, Emory University

Sarah Poss

Department of Psychology, Emory University

Abstract

Hand preferences for a coordinated bimanual task were assessed in 109 chimpanzees (*Pan troglodytes*). Hand preference was evaluated for 4 test sessions using bouts and frequencies of hand use to compare the sensitivity of each level of analysis in evaluating individual variation in handedness. Overall, significant population-level right-handedness was found using several different measures of hand use. Handedness indices based on bouts and frequencies were highly and significantly correlated. Moreover, hand preferences were consistent across tests despite efforts to situationally bias preference during each test. Taken together, these data do not support the view that bouts are a better level of analysis for evaluating hand preference. The results further suggest that hand preferences for coordinated bimanual actions are not influenced by situational factors and may reflect an inherent specialization of the left hemisphere for motor skill.

The issue of whether nonhuman primates exhibit population-level handedness has been a topic of historical and recent debate (Ettlinger, 1988; Fagot & Vauclair, 1991; MacNeilage, Studdert-Kennedy, & Lindblom, 1987; Marchant & McGrew, 1991; Ward & Hopkins, 1993; Warren, 1980). Population-level handedness exists when a statistical majority of individuals within a

sample display the same directional bias in hand use. The historical view held that handedness was bimodally distributed in nonhuman species including primates (Warren, 1980), but this view has recently been challenged by a host of behavioral Studies (see Bradshaw & Rogers, 1993; Hook-Costigan & Rogers, 1997; Hopkins, 1996; Hopkins & Morris, 1993; Lehman, 1993; Ward, Milliken, & Stafford, 1993, for reviews). Of specific interest to this article is the evidence of population-level right-handedness in chimpanzees and other great apes. Some have argued that there is a 2:1 ratio of right- to left-handed individuals (Corballis, 1997; Hopkins, 1999b; Hopkins & Pearson, 2000). In contrast, others have argued that the evidence is weak for population-level right-handedness in apes and that some Studies reporting evidence of population-level right-handedness are methodologically or statistically flawed (McGrew & Marchant, 1997).

Presently, the debate over whether great apes (and other nonhuman primates) exhibit population-level hand preference centers on two issues, both of which are subject to different interpretation. One issue is whether population-level right-handedness is restricted to captive populations of apes, and this issue is not addressed in this article. The second issue, which is addressed in this article, is whether the use of frequencies contrasted with bouts of lateralized behavior reflects the same or different manifestations of lateral bias at the individual and population level. Specifically, McGrew and Marchant (1994, 1997), as well as others (Boesch, 1991; Byrne & Byrne, 1991), have argued that bouts are a better measure of laterality in hand use than the use of the raw frequencies. The central premise of this argument, outlined by McGrew and Marchant (1997), is that when using raw frequencies, there is not true independence of each individual hand use event, and therefore this can lead to inflated and potentially skewed observations about the preferential use of the left and right hands. For example, if there were peanuts scattered randomly on the ground, a chimpanzee or other primate might pick up and eat seven consecutive times with its left hand. According to McGrew and Marchant (1997), this should only be considered one "bout" of left hand use and not seven left-hand reaches because there were no postural or intervening motor actions that precluded the subject's perseverative use of one hand. According to McGrew and Marchant (1997), using frequencies in this case would inflate the number of observations of left-hand use and potentially lead to the misclassification of subjects as either left- or right-handed based on skewed data.

The argument put forward by McGrew and Marchant (1997) for the use of bouts is a valid one, but it is not without some problems. For instance, Hopkins (1999b) has argued that asymmetries can exist in bout lengths that are not captured by the measurement of bouts alone. For example, a subject could reach for a piece of food with its left hand 10 times for each of 10 bouts and reach with its right hand 2 times for each of 10 bouts. Using bouts alone, this subject would be ambiguously handed (10 left- and 10 right-handed responses) but would be left-handed on the basis of its frequencies (100 left- and 20 right-handed responses). The reason for this difference is that the subject shows an asymmetry in bout length (number of responses per bout). Thus, Hopkins (1999b) argued that bouts, by themselves, are not the best measure of hand preference and should not be used as the sole measure of lateral bias.

The issue of whether the bouts contrasted with frequencies better reflect inherent biases in hand use is by no means trivial because contrasting views of the importance of this issue have led to differing interpretations of the published data on hand preference in nonhuman primates. In their review article on the evidence of population-level handedness in nonhuman primates, McGrew and Marchant (1997) selected data from published articles based on whether investigators used bouts or raw frequencies in the evaluation of hand preference. Thus, data from Studies that McGrew and Marchant (1997) viewed as lacking sufficient control over independence of observations were excluded from their analysis and led them to conclude that there was no convincing evidence of population-level hand preference in nonhuman primates.

This conclusion stands in strong contrast to other published interpretations of most of the same data and literature (Bradshaw & Rogers, 1993; Hopkins, 1996, 1999b; Ward & Hopkins, 1993; Westergaard, Kuhn, & Suomi, 1998; Westergaard & Suomi, 1996).

Unfortunately, most of these arguments are theoretical rather than based on solid, empirical data because there has been no attempt to quantify and compare hand preference findings using both bouts and frequencies as the level of analysis in the evaluation of hand preference. The primary purpose of this study was to assess hand preference for a coordinated bimanual tube task (TUBE), referred to as the TUBE task, using both bouts and frequencies in a sample of chimpanzees. We selected the TUBE task because this measure has previously been used in chimpanzees and was reported to elicit a population-level right-hand bias on the basis of frequencies in hand use (see Hopkins, 1995, 1999a). The data from this original article were excluded from the review article and meta-analyses by McGrew and Marchant (1997) because they were not considered to have met those researchers' criteria for independence of data points. Thus, in this study, hand preferences on the TUBE task were reassessed in largely the same sample of chimpanzees as the original study reported, but handedness indices based on bouts and frequencies of hand use were recorded during four separate tests. If bouts contrasted with frequencies in hand use lead to different manifestations of hand preference, then handedness indices derived from these two measures should not be correlated and should lead to different interpretations of the findings.

Method

Subjects

The subjects were 109 chimpanzees (*Pan troglodytes*) housed at the Yerkes Regional Primate Research Center (YRPRC) of Emory University. There were 60 females and 49 males, and the subjects ranged in age from 4 to 47 years ($M = 15.51$ years, $SD = 10.02$). Within the female sample, there were 35 mother-reared and 25 nursery-reared subjects. For the male sample, there were 17 mother- and 32 nursery-reared subjects. Mother-reared chimpanzees were those reared by their biological, conspecific mother for more than 30 days of life. Nursery-reared subjects were those that were brought to the YRPRC nursery before 31 days of life. The standard protocol for nursery rearing chimpanzees has been described in detail elsewhere (Bard, 1996). All of the chimpanzees lived in social groups ranging from 2 to 16 individuals. Cage sizes varied according to group size, but all of the cages met minimum standards as required by federal regulations.

Procedure

Hand preference was assessed using a task designed to elicit coordinated bimanual actions, referred to as the TUBE task. The procedure for this task has been described in detail elsewhere (Hopkins, 1995). Briefly, peanut butter was smeared on the inside edge of polyvinyl chloride (PVC) tubes approximately 15 cm in length and 2.5 cm in diameter. Peanut butter was smeared on both ends of the PVC pipe and was placed far enough down the tube such that the chimpanzees could not lick the contents completely off with their mouths but rather had to use their fingers to remove the substrate. The PVC tubes were handed to the subjects in their home cages, and a focal sampling was used to collect individual data from each subject. The hand and finger used to extract the peanut butter were recorded as either right or left by the experimenter. Data were collected until the subjects dropped the tube, stopped extracting peanut butter for a period of 10 s, or returned the PVC pipe to the experimenter. The 10-s limit did not include instances in which the subjects were locomoting with the PVC pipe. Rather, this time limit was specific to instances in which they had the PVC pipe in hand, were stationary in positional behavior, and were not attempting to feed (usually because of the absence of any remaining peanut butter).

All but 7 subjects were tested on four occasions, and specific attention was paid to the hand used to take the tube by the subject. Specifically, for two tests, the subjects were required to take the tubes with their left hands. For the remaining two tests, the subjects were required to take the tubes with their right hands. The order of presentation of the tubes to either the left or right hand was randomized across subjects. For the remaining 7 subjects, two test sessions were obtained with the hand taking the tube counterbalanced in each case. Most of the subjects received two test sessions per day and were tested on 2 consecutive days. A 5- to 10-min interval separated each test session, during which time the PVC pipes were retrieved from the chimpanzees, cleaned, and refilled with peanut butter. For a smaller sample of subjects, all four test sessions were conducted in 1 day. Most of these subjects were housed in circumstances or were involved in other research projects such that only limited time was available to access them for data collection. Hand use while removing the peanut butter was recorded in two ways. First, bouts of right- and left-hand use were recorded. Bouts of hand use were separated by any event that would result in the potential change in the use of one hand or the other. In this study, bouts were separated by either the chimpanzees' movement to a different area to resume feeding or by subjects' rotation of the tube to access the peanut butter in the opposite end. With respect to rotation of the tube, a change in bout was only recorded when the tube was physically rotated and not when the subject simply rotated its wrist to access the peanut butter in the tube. In addition to bouts, we also recorded the frequency of hand use each time a subject removed peanut butter from the tube. Each time a chimpanzee reached into the tube with its finger, extracted peanut butter, and brought it to its mouth, the hand used was recorded as left or right.

Data Analysis

Hand preferences were characterized several different ways in this study. First, a bout handedness index (BHI) was calculated for each of the four test sessions (BHI1, BHI2, BHI3, and BHI4) as well as for the overall number of bouts (SUM-BHI) by subtracting the number of left bouts from the number of right bouts and dividing by the total number of bouts. Second, as with the bout data, a frequency handedness index (FHI) was calculated for each of the four test sessions (FHI1, FHI2, FHI3, and FHI4), as well as for the overall frequency (SUM-FHI), using the same overall formula described above. Third, a mean bout handedness index (MEAN-BHI) and mean frequency handedness index (MEAN-FHI) were derived by taking the average of the four handedness indices derived for each test session. These values were derived because the number of observations of hand use varied from one test session to another, and therefore, based on the raw data, a greater number of left- or right-handed observations within a test session could skew the overall handedness scores (SUM-BHI and SUM-FHI). Fourth, based on the total left- and right-hand bouts and frequencies, *z* scores were used to evaluate whether the hand preferences of individual subjects deviated significantly from chance. This is the procedure most frequently used in the nonhuman primate literature (see Hopkins, 1999b). Subjects with *z* scores greater than 1.96 or less than -1.96 were classified as right- and left-handed, respectively. All other subjects were classified as ambiguously handed. Finally, a second procedure was used to classify subjects as left-handed, right-handed, or ambiguously handed based on the variability in overall handedness scores. For both the overall bout and frequency data (SUM-BHI, SUM-FHI), the standard error of the sample distribution was calculated. Subjects that had handedness index values that were 2 *SEs* above or below zero were classified as ambiguously handed. Subjects with handedness index values above 2 *SEs* were classified as right-handed, and subjects with handedness indices more than 2 *SEs* below the mean were classified as left-handed. This classification scheme allowed for comparison of the distribution of handedness classifications that was not influenced by the total number of observations, as is the case with *z* scores. For all analyses, alpha was set to $p < .05$. For all handedness indices, positive values reflected right-hand biases, and negative values reflected left-hand biases. The absolute value of the handedness score reflected the magnitude of hand preference.

Results

Descriptive Statistics and Correlations Between Bouts and Frequency of Hand Use

Shown in Table 1 are the mean number of bouts and frequencies for each test session and for the overall data. In addition, the overall mean number of responses per bout for the left and right hands are presented in Table 1. A significant positive correlation was found between the SUM-BHI and SUM-FHI scores, $r(107) = .920, p < .001$, as well as between the MEAN-BHI and MEAN-FHI scores, $r(107) = .958, p < .001$. This indicates that handedness indices based on bouts and frequencies are sensitive to the same degree of lateral bias in hand use. In addition to the assessment of consistency of measures based on the overall and mean handedness scores, correlations were performed between the test sessions separately for the BHI and FHI scores. These data can be seen in Table 2. For these analyses, the 7 subjects for which data were collected in only two test sessions were omitted. For both the BHI and FHI scores, significant positive correlations were found across all four test sessions, indicating consistent hand use across tests.

Population-Level Handedness

Depicted in Figure 1 are the mean handedness scores for the bout and frequency measures of hand use for each test session as well as the SUM-BHI, SUM-FHI, MEAN-BHI, and MEAN-FHI scores. Significant population-level right-handedness was found for the SUM-BHI, $t(108) = 2.65, p < .01$; SUM-FHI, $t(108) = 2.08, p < .05$; MEAN-BHI, $t(108) = 2.69, p < .01$; and MEAN-FHI, $t(108) = 2.38, p < .02$, measures as revealed by one-sample t tests. As can be seen in Figure 1, the results were largely consistent across all test sessions for both bouts and frequencies of hand use. In terms of the categorical data based on z scores, when using frequencies in hand use, there were 54 right-handed, 22 ambiguously handed, and 33 left-handed chimpanzees. This distribution differed significantly from chance, $\chi^2(1, N = 109) = 14.49, p < .01$, as revealed by a chi-square goodness-of-fit test. A subsequent chi-square goodness-of-fit test revealed that the number of right-handed individuals was significantly greater than the number of left-handed, $\chi^2(1, N = 87) = 5.07, p < .03$, and ambiguously handed individuals, $\chi^2(1, N = 76) = 13.47, p < .01$. When using z scores based on bouts of hand use as the basis for hand preference classification, there were 15 left-handed, 70 ambiguously handed, and 24 right-handed subjects, a distribution that differs significantly from chance, $\chi^2(2, N = 109) = 47.91, p < .001$. The number of ambiguously handed subjects was significantly higher than the number of left-handed, $\chi^2(1, N = 85) = 22.51, p < .01$, and right-handed, $\chi^2(1, N = 94) = 35.49, p < .01$, subjects. However, there was no significant difference in the number of left- and right-handed subjects, $\chi^2(1, N = 39) = 2.08, ns$.

For the second classification criterion, the mean handedness index values for bouts and frequencies were .11 and .12, with standard error values of .04 and .05, respectively. Thus, in the second classification schema, for the frequency data, subjects with SUM-FHI values between $-.1599$ and $.1599$ were classified as ambiguously handed. Subjects with SUM-FHI values greater than $.1599$ were classified as right-handed, and subjects with SUM-FHI values less than $-.1599$ were classified as left-handed. For the bout data, subjects with SUM-BHI values between $-.1199$ and $.1199$ were classified as ambiguously handed. Subjects with SUM-BHI values greater than $.1199$ were classified as right-handed, and subjects with SUM-BHI values less than $-.1199$ were classified as left-handed. On the basis of this classification criterion, the numbers of right-, left-, and ambiguously handed subjects based on the frequency data were 56, 32, and 21, a distribution that differs significantly from chance, as revealed by a goodness-of-fit test, $\chi^2(1, N = 109) = 17.67, p < .001$. For the bout data, the numbers of right-, left-, and ambiguously handed subjects were 56, 29, and 24, a distribution that also differs from chance, as revealed by a goodness-of-fit test, $\chi^2(1, N = 109) = 16.31, p < .001$.

Asymmetries in Mean Bout Length

Whether the chimpanzees showed asymmetries in the mean bout length for each hand as a function of their hand preferences was evaluated in the next analysis. For each subject, the total frequencies of left- and right-hand use were divided by the total number of bouts of left- and right-hand use to derive a measure of mean bout length. The mean bout lengths for the left and right hands were compared in chimpanzees classified as left-handed, ambiguously handed, and right-handed on the basis of their individual z score. Four subjects were omitted from this analysis (three right-handed and one left-handed) because they showed exclusive use of one hand, and therefore a mean bout length could not be determined for the nondominant hand. For this analysis, a mixed-model analysis of variance was used, with mean bout length of the left and right hand serving as the repeated measure and hand preference classification (left-, ambiguously, or right-handed) serving as the between-groups variable. The mean bout lengths for the left and right hands for chimpanzees classified as left-handed, ambiguously handed, and right-handed can be seen in Figure 2. A significant two-way interaction was found between hand preference classification and mean bout length for the left and right hands, $F(2, 102) = 15.96, p < .001$. Post hoc analysis was performed using paired t tests. The mean bout length for the left hand was significantly greater than that for the right hand for subjects classified as left-handed, $t(31) = 4.83, p < .001$. In contrast, for subjects classified as right-handed, the mean bout length for the right hand was significantly greater than that for the left hand, $t(50) = -3.17, p < .004$. In ambiguously handed subjects, no difference in bout length was found between the left and right hands.

Longitudinal Consistency in Hand Use

For this analysis, the SUM-FHI data were correlated with the handedness indices based on the total frequencies collected for the article by Hopkins (1995) using a Pearson product-moment correlation. This analysis allowed for assessment of consistency in hand use over a 6-year period. A significant positive correlation was found, $r(106) = .55, p < .001$, indicating that subjects who preferred to use their right or left hand in 1995 still preferred to use that same hand in 2000.

Discussion

There were four main findings in this study. First, handedness indices as assessed by both bouts and frequency of hand use were highly correlated and comparable in their sensitivity to individual and population variability in hand preference. Second, population-level right-handedness was evident for the TUBE task, irrespective of the level of analysis and manner in which hand preferences were characterized. Third, hand preferences, as assessed by bouts or frequencies in hand use, were consistent across test sessions. Finally, hand preferences were consistent across a 6-year test-retest time period.

One aim of this study was to evaluate and compare the sensitivity of using bouts contrasted with using frequencies of hand use in the assessment of hand preference. The findings clearly indicated that in the context of the TUBE task, measuring bouts contrasted with frequencies made absolutely no difference in the characterization of hand preferences of the subjects. Support for this conclusion came from the facts that the correlation between the measures was very high ($>.90$) and the handedness indices derived for each set of measures were nearly identical. Furthermore, analyses for population-level handedness using the SUM-BHI, SUM-FHI, MEAN-BHI, and MEAN-FHI all produced identical results (i.e., population-level right-handedness). Taken together, these results do not support the suggestion by McGrew and Marchant (1997) that bouts are the best measures of hand preference. The cumulative results also do not support the practice by McGrew and Marchant (1997) of excluding Studies in their meta-analyses that do not meet their criteria of using bouts as the level of analysis of hand use.

The most relevant difference between the use of bouts and frequencies as the level of analysis for hand use was in the evaluation of individual and population-level hand preferences using z scores. Using frequencies, there were significantly more lateralized than nonlateralized subjects, and there were significantly more right-handed than there were ambiguously-handed or left-handed subjects. In contrast, there were significantly more nonlateralized than lateralized subjects and there was no difference between the number of left- and right-handed subjects when using bouts as the level of analysis. This finding is not consistent with the handedness indices based on frequencies and bouts, nor is it consistent with the findings based on the classification scheme that was derived based on the degree of variation in handedness values. This could be interpreted as support for the arguments in favor of the use of bouts put forward by McGrew and Marchant (1997); however, there are several problems with that interpretation. First, z scores are sensitive to sample size, and there may not have been enough observations of bout use to reach statistical significance with this measure compared with the case of the raw frequencies. However, it is likely that had we continued to test the subjects, eventually, enough bout data would have been collected, and they would have approximated the frequency data (based on the strong, significant, positive correlation in handedness index measures). The second issue of interpretation has to do with the use of z scores in the evaluation of individual hand preferences. There is no strong rationale for their use, and arguably, they are unnecessary and a less sensitive measure of hand preference compared with handedness indices. The practice of using z scores to classify subjects as left- or right-handed reduces statistical power because the data are being transformed from a continuous (such as handedness indices) to a nominal scale of measurement, a type that is less sensitive. The dichotomy of these two approaches is most evident when comparing the SUM-BHI and SUM-FHI scores with the results using the classification scheme based on z scores. The SUM-BHI ($M = .112$) and SUM-FHI ($M = .113$) scores are nearly identical, whereas comparing the results of the hand preference classification data is not nearly as consistent. Moreover, using a different classification scheme that was derived based on the degree of variation observed in the sample yielded a significant population bias. These findings suggest that there is much more validity to the use of handedness indices or other classification schemes based on either bouts or frequencies than to the use of classification schemes based on individual z scores. As Hopkins (1999b) has articulated, z scores are useful when the number of observations is large and equal between subjects, but there are often circumstances in Studies with nonhuman primates that prohibit the collection of equal sample sizes. We emphasize that there are other alternatives that are both practical and perfectly valid from a methodological and statistical standpoint.

The operational definition of a bout in hand use adopted in the study was created to address the specific criticisms that others have articulated concerning the measurement of handedness for the TUBE task (see McGrew & Marchant, 1997). Of course, the issue of bouts can be extended outside of this context and could be considered at other levels of analysis. For example, a bout of hand use could be characterized across days or weeks or months and does not have to be restricted to hand use within a given test session. This is a valid point, but we believe that it highlights the problem with the use of bouts. Bouts are arbitrary units of measurement imposed upon a sequence of ongoing behavior. In the context of hand use for the TUBE task (and probably many other measures), we could have adopted any number of criteria for distinguishing between events that would have constituted bouts or nonbouts of hand use. In our view, the simplest and most parsimonious level of analysis for hand use is to record frequency. This is a perfectly valid measure so long as there are not procedural factors that bias the frequency of hand use, other than those imposed by the subject.

In terms of recording frequency of hand use, it has been argued that hand use can be perseverative, that individual events are not independent, and that this inflates sample sizes and increases the likelihood of finding significant hand preferences (Byrne & Byrne, 1991; Lehman, 1993; McGrew & Marchant, 1997). All of these are valid issues, but there is no

reason to assume that the results would yield an asymmetrically distributed population. In other words, when recording frequency of hand use, the probability of having a skewed distribution to the left or right is equal and should result in a bimodal distribution of hand use, all things being equal.

The findings reported in Table 1 and depicted in Figure 2 indicate that there was consistency in hand preference across test sessions using both bouts and frequencies as the level of analysis. These results are by no means trivial because the design of this study required that the tube be taken by the subjects with either their left or right hand. Thus, we intentionally created the potential for biased and bidirectional hand use for this task. If the chimpanzees simply removed the peanut butter with the hand opposite that used to take the tube, then the correlations should have been significant but negative, rather than positive. This suggests that the preferences expressed by the chimpanzees were not situationally determined, as some have proposed might be the case for those Studies in which population-level hand preference has been reported (McGrew & Marchant, 1997; but see Hopkins & Carriba, 2000). These findings further suggest that the hand preferences are expressed because of endogenous factors, perhaps related to a specialization of the left hemisphere for motor skill. This hypothesis warrants further research, perhaps using brain imaging technologies that are now being used with nonhuman primates, including great apes (e.g., Hopkins & Marino, 2000; Hopkins, Marino, Rilling, & MacGregor, 1998; Pilcher, Hammock, & Hopkins, 2000; Zilles et al., 1996).

Finally, the correlation between the data originally reported by Hopkins (1995) and those reported in this article was significant and positive. These results cannot be attributed to learning associated with reinforcement history because the subjects were not tested on the TUBE task during the intervening 6-year period. Thus, these results suggest that the TUBE task is a stable measure of hand preference.

In conclusion, the cumulative results of this study suggest that bouts rather than frequencies are not necessarily a better level of analysis in the evaluation of hand preference in chimpanzees (and probably other nonhuman primates). This is not to suggest that perseveration in responding or a lack of independence of hand use cannot influence the assessment or interpretation of hand preference. There very well may be situations or tasks in which this issue becomes important, but based on these findings, they are not relevant issues for the TUBE task. This may be due, in part, to the fact that the TUBE task is a relatively stable measure of hand preference and does not appear to be influenced by situational factors. Thus, the point at which perseveration of responses or a lack of independence of data points becomes relevant in the assessment of hand preference is likely associated with the degree to which the measure is reliably expressed by the subject and influenced by situational factors.

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Figure 1.
Mean handedness scores for each of the four test sessions, the summary (Sum) data, and the mean index data for bouts and frequencies.

Figure 2.
Mean bout length for the left and right hands for chimpanzees classified as left-handed, ambiguously handed, and right-handed.

Table 1
Descriptive Statistics for Bouts and Frequency of Hand Use

Measure	<i>M</i>	<i>SE</i>
Bout 1	6.73	0.38
Bout 2	6.96	0.41
Bout 3	5.19	0.28
Bout 4	5.75	0.31
Total bout	23.78	0.95
Frequency 1	31.12	1.62
Frequency 2	32.25	1.63
Frequency 3	27.79	1.61
Frequency 4	30.45	1.78
Total frequency	118.52	5.11
Mean left-hand responses per bout	5.27	0.29
Mean right-hand responses per bout	5.24	0.31

Table 2
Correlation Coefficients for the Four Tests of Hand Use Using Bouts and Frequency as the Level of Analysis

Test	1	2	3	4
Bouts				
1. Test 1	1.00			
2. Test 2	.529***	1.00		
3. Test 3	.529***	.522***	1.00	
4. Test 4	.508***	.545***	.535***	1.00
Frequency				
1. Test 1	1.00			
2. Test 2	.570***	1.00		
3. Test 3	.518***	.535***	1.00	
4. Test 4	.502***	.566***	.601***	1.00

Note. *df* = 105 for all comparisons.

p < .001.